



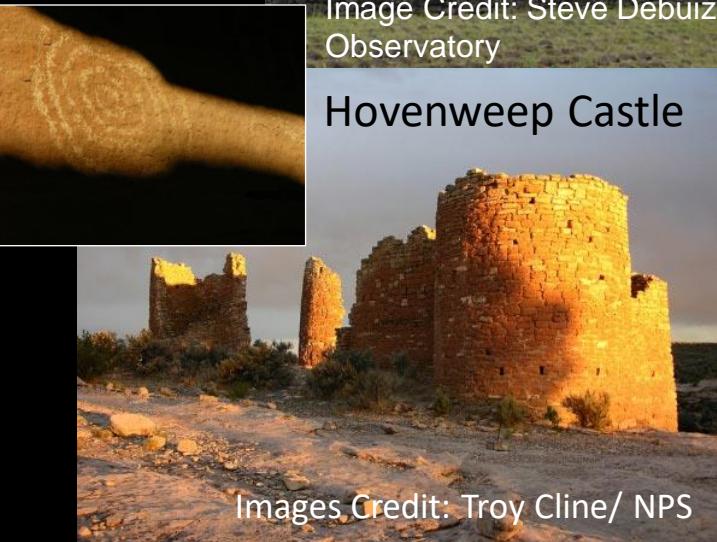
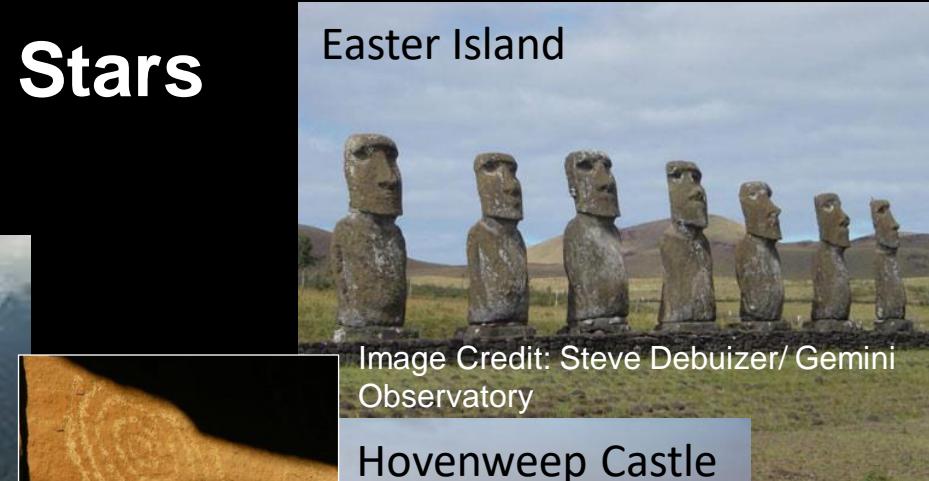
Multigenerational Interstellar Exploration with Small Spacecraft

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Civilizations Studying the Sun, Moon, and Stars



Curiosity and Theism



Image Credit: garethwiscombe/
Wikimedia Commons [5]



Image Credit: NASA



Image Credit: NASA



Image Credit: NASA

Philosophy and Astronomy

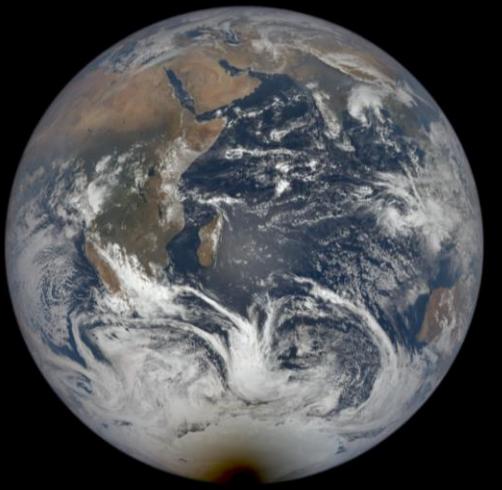


Image Credit: NASA

Geocentric to Heliocentric

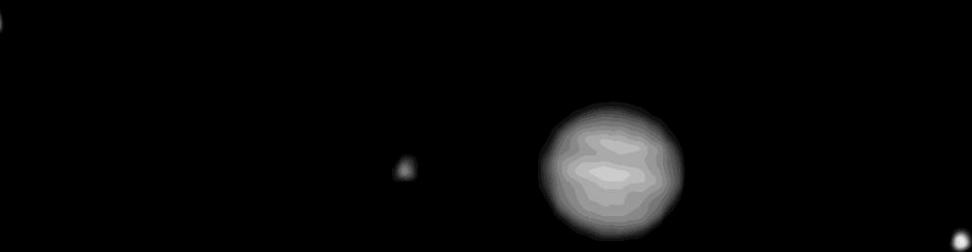


Image Credit: NASA/University of Arizona

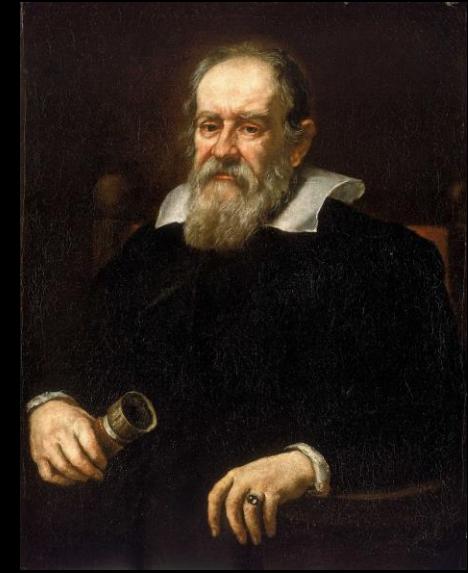


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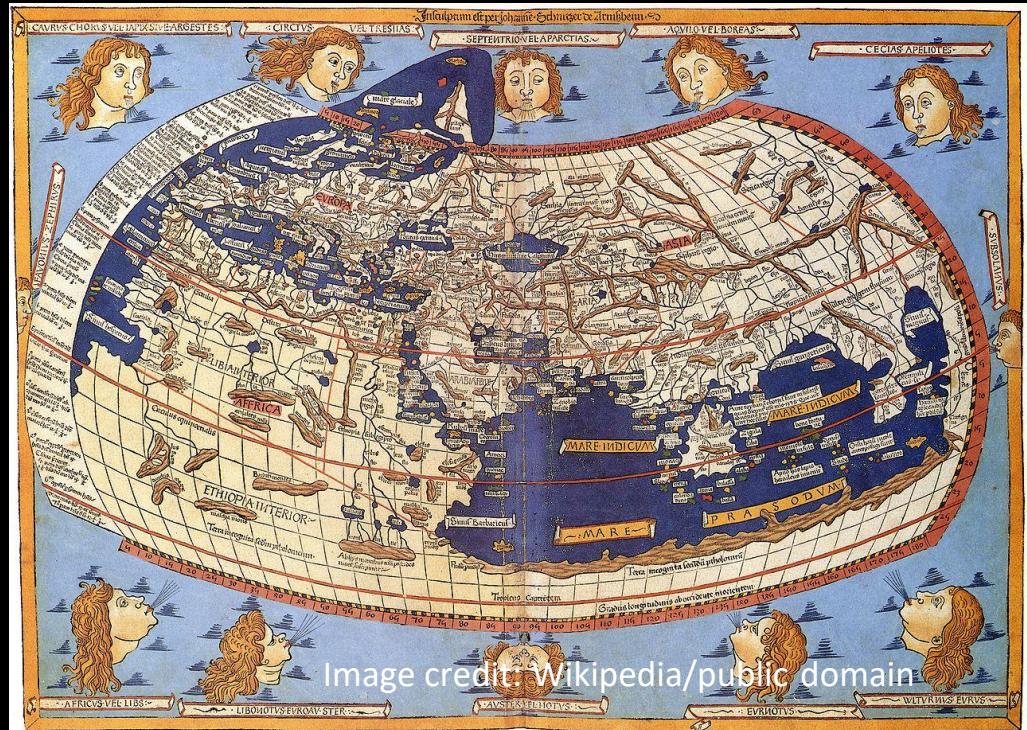
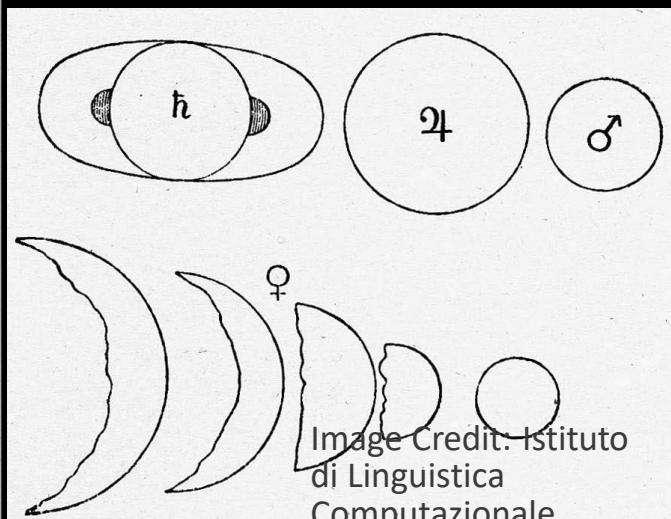
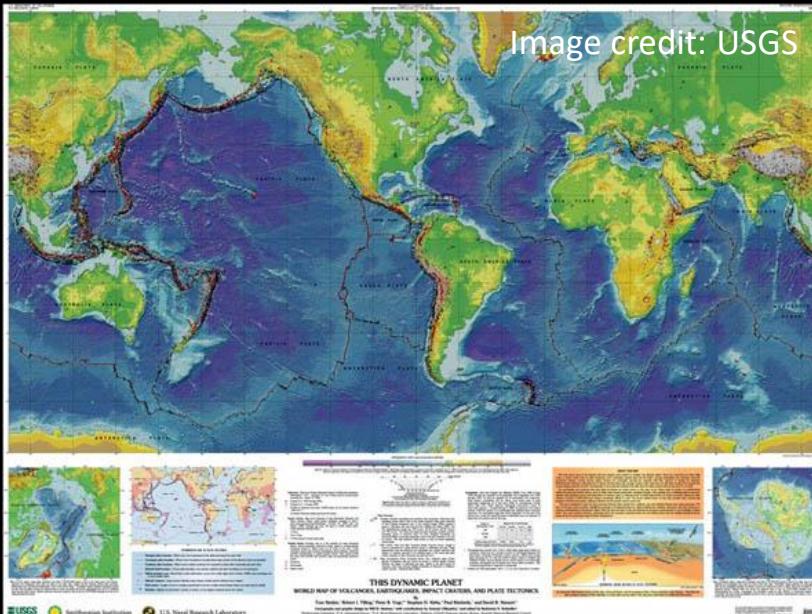
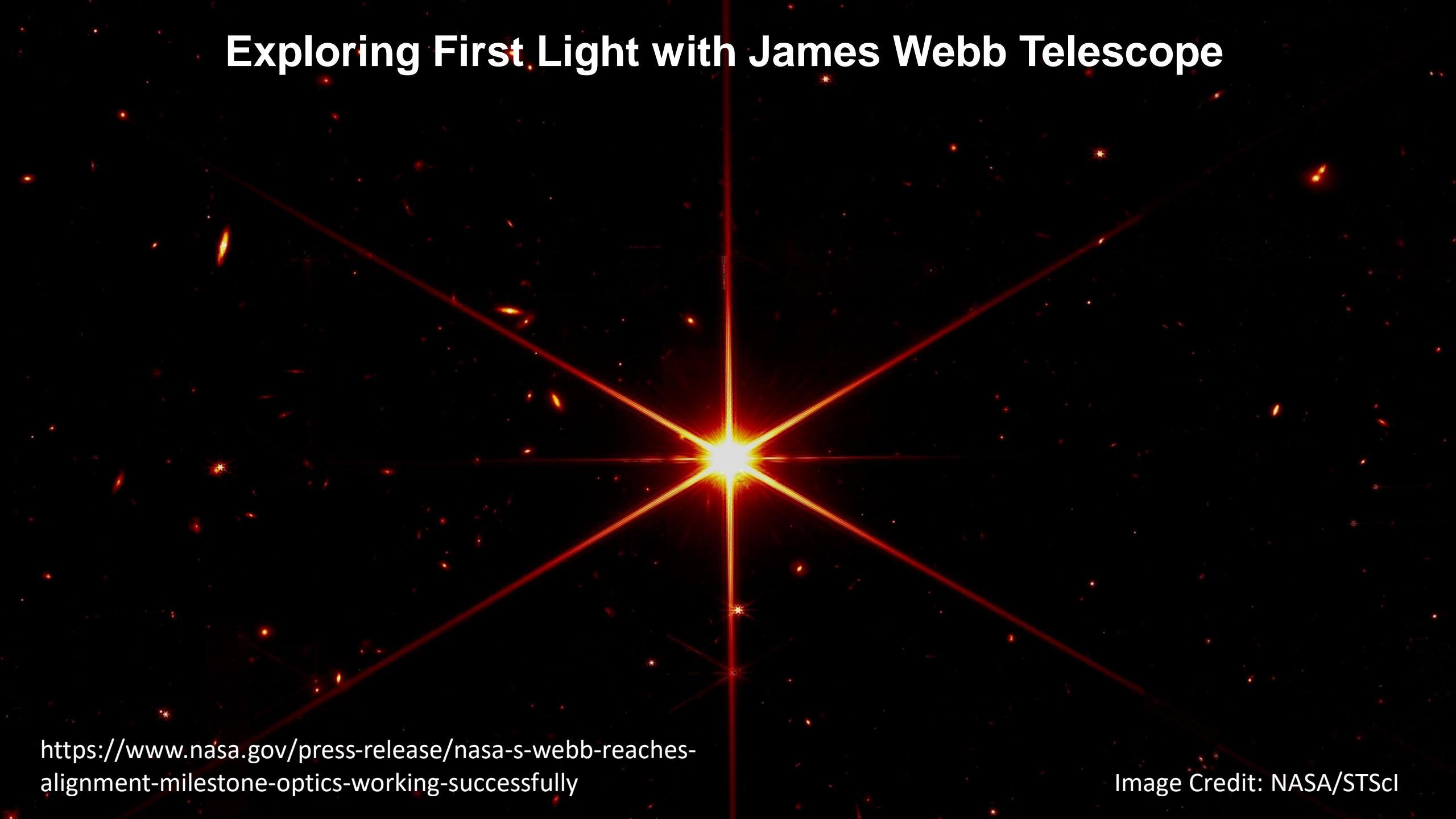


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Exploring First Light with James Webb Telescope



<https://www.nasa.gov/press-release/nasa-s-webb-reaches-alignment-milestone-optics-working-successfully>

Image Credit: NASA/STScI

Exploring the Solar System

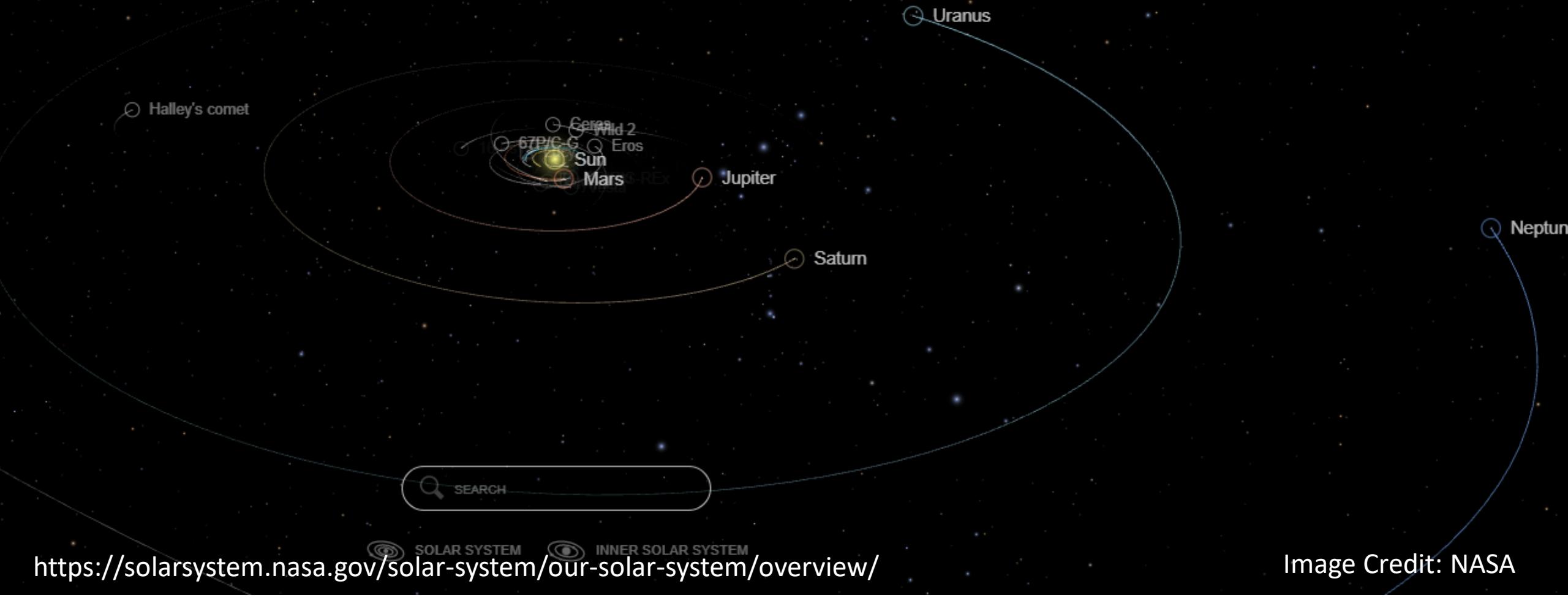


Image Credit: NASA

Solar Exploration Missions

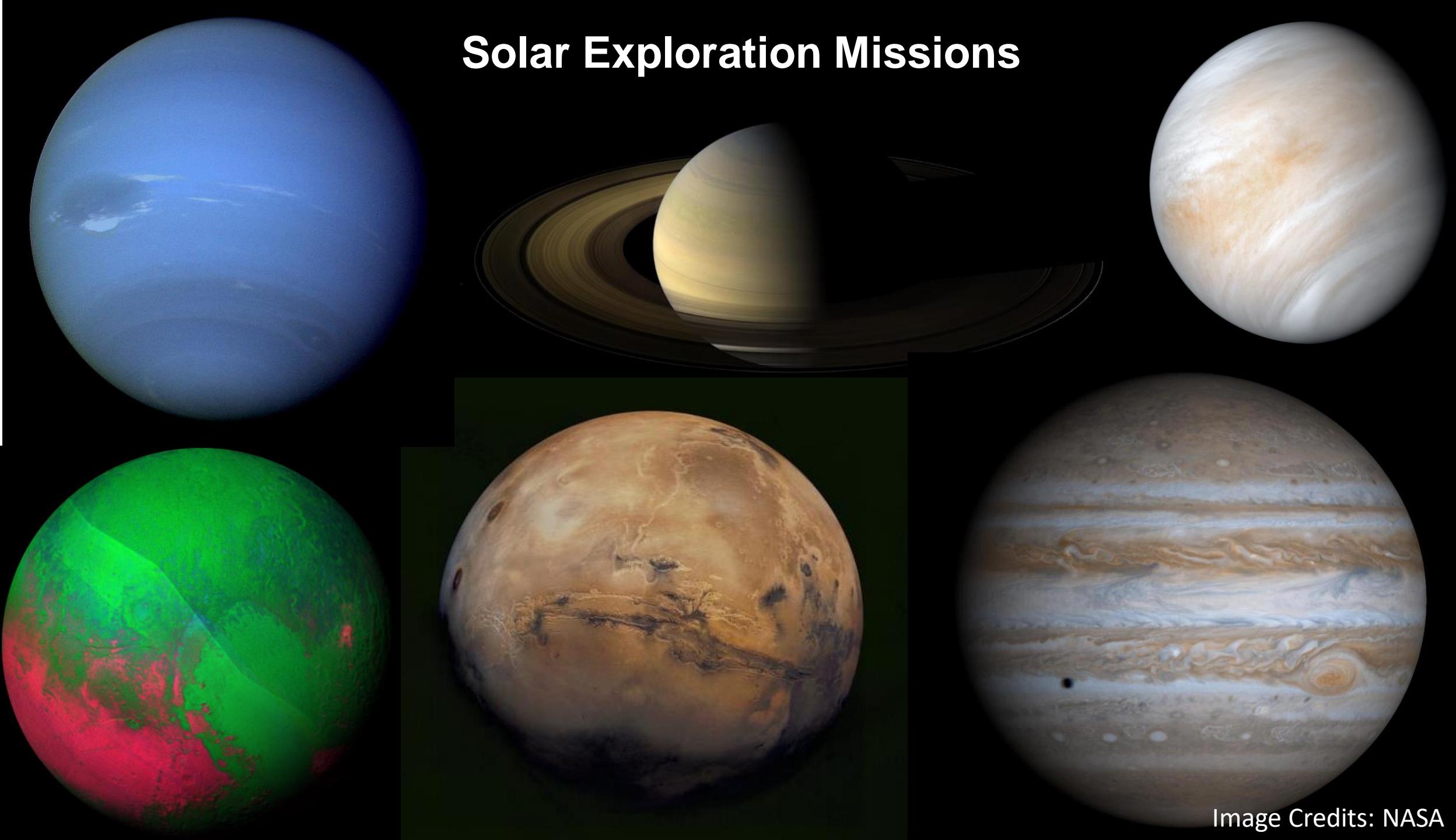
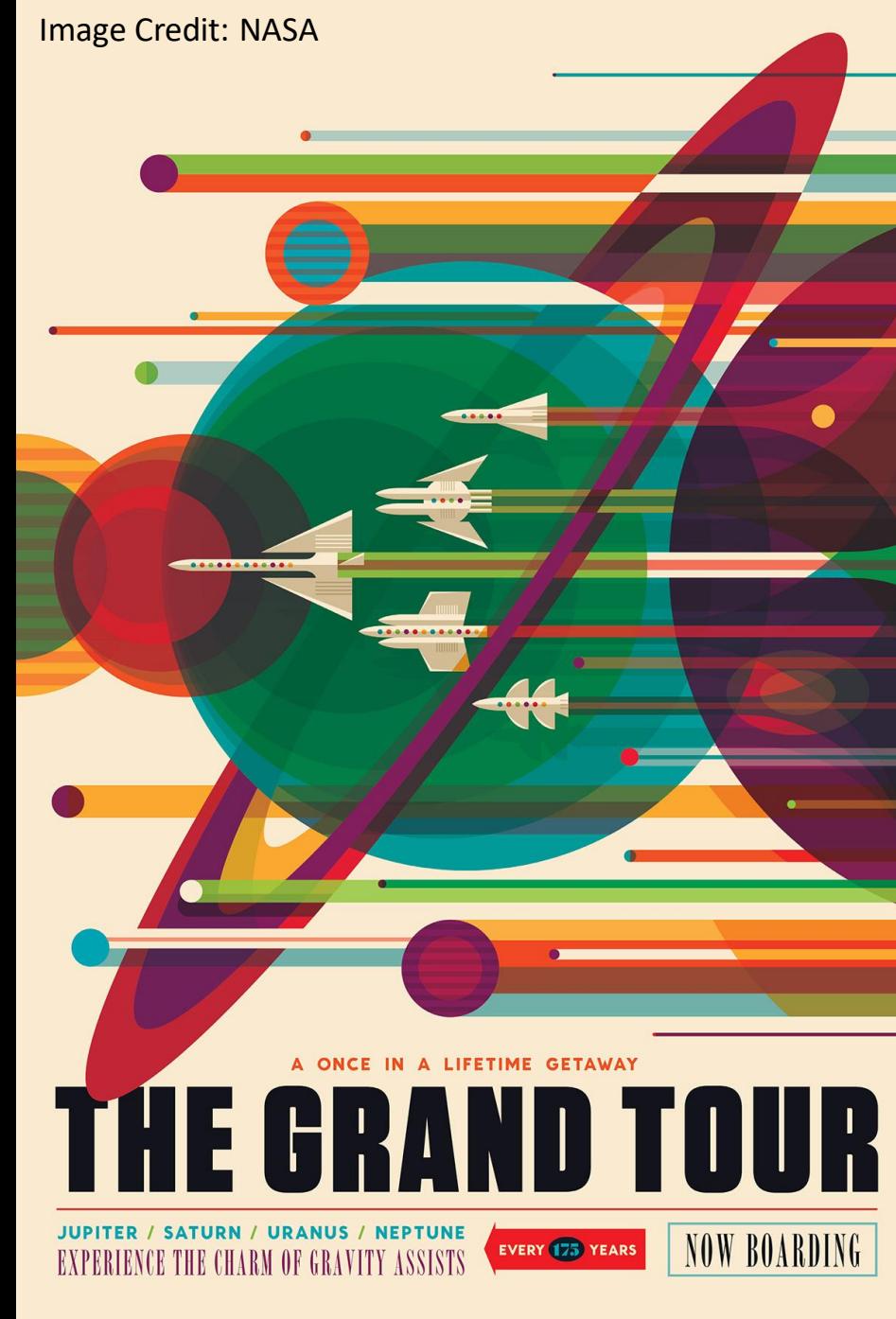
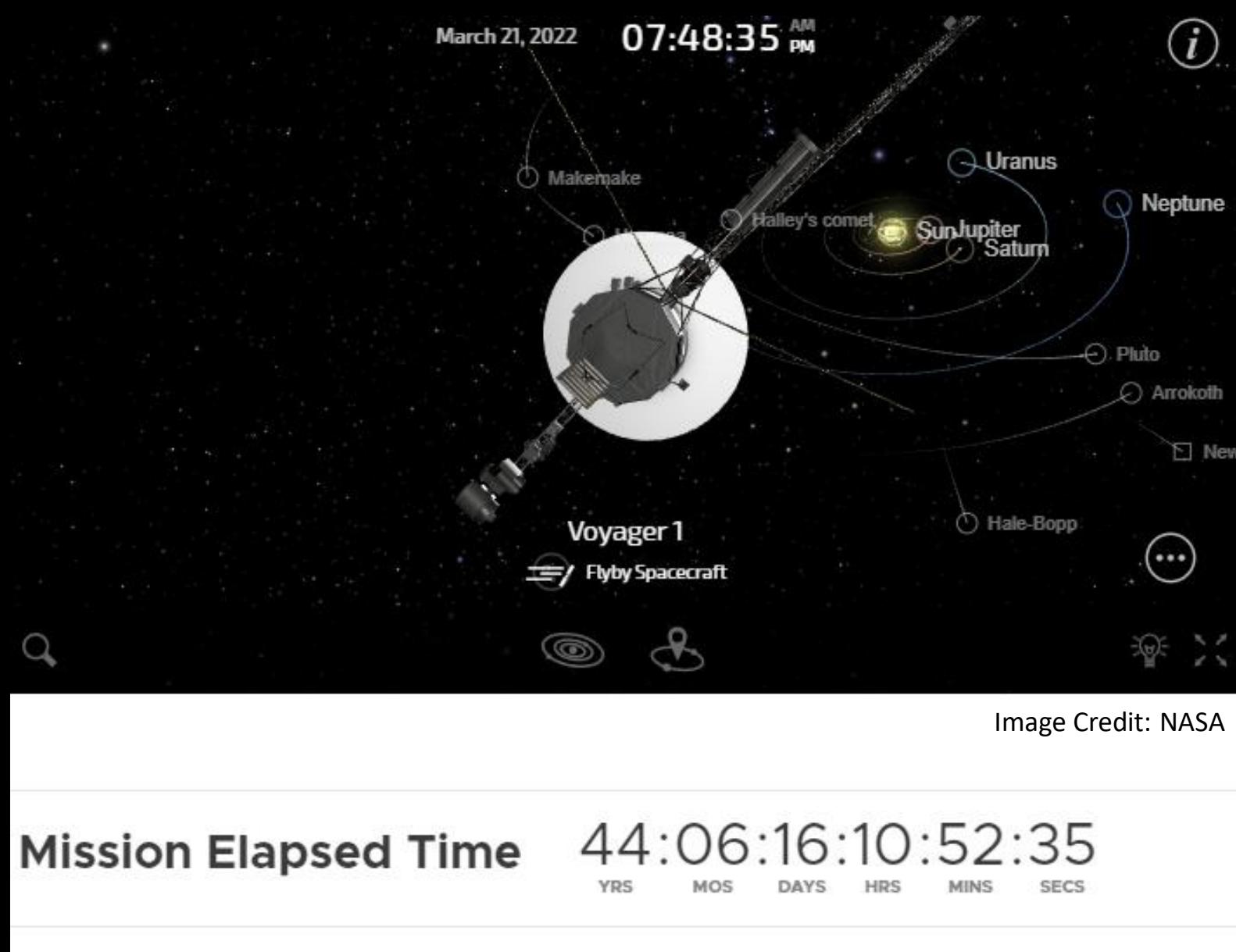


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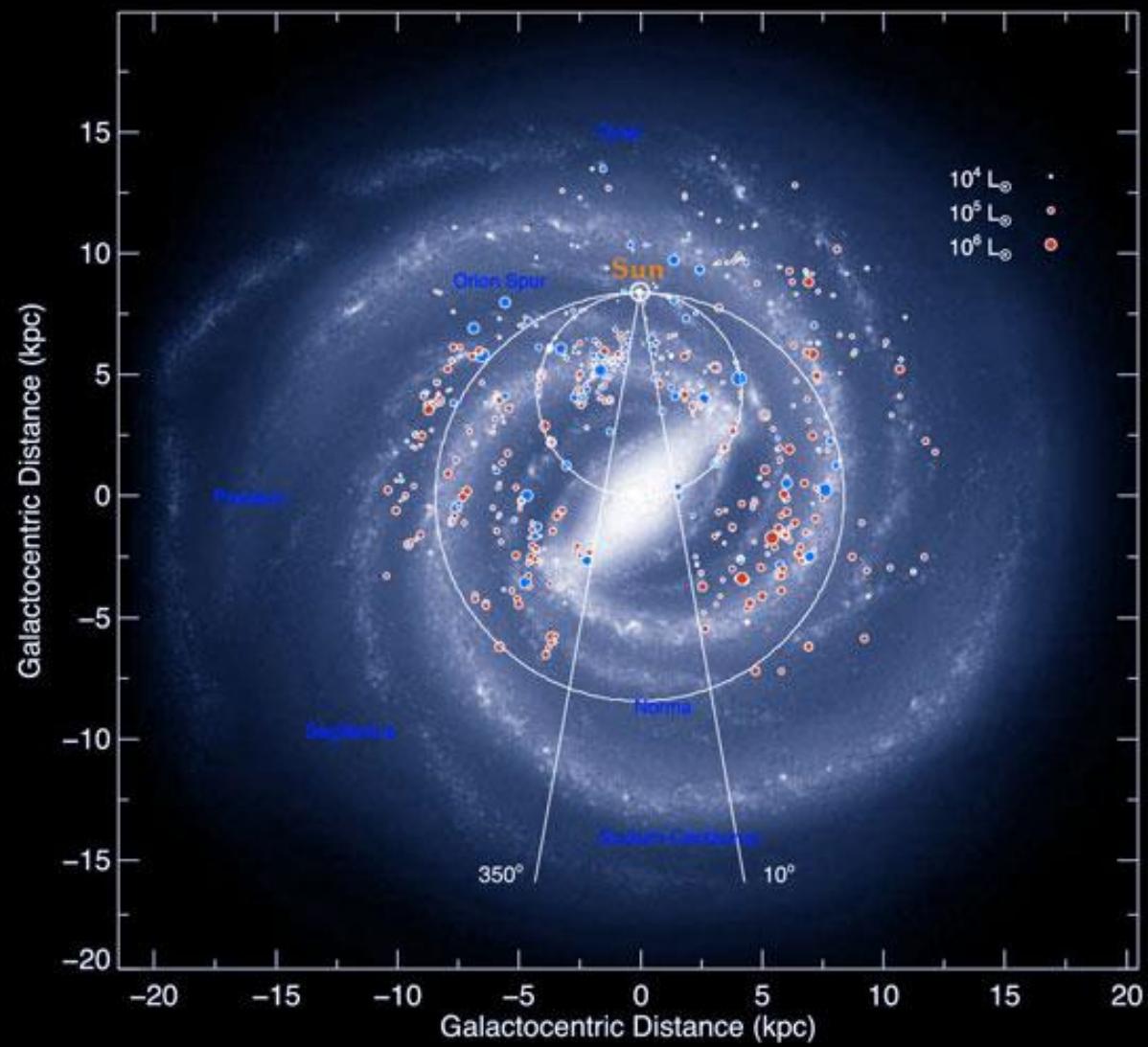
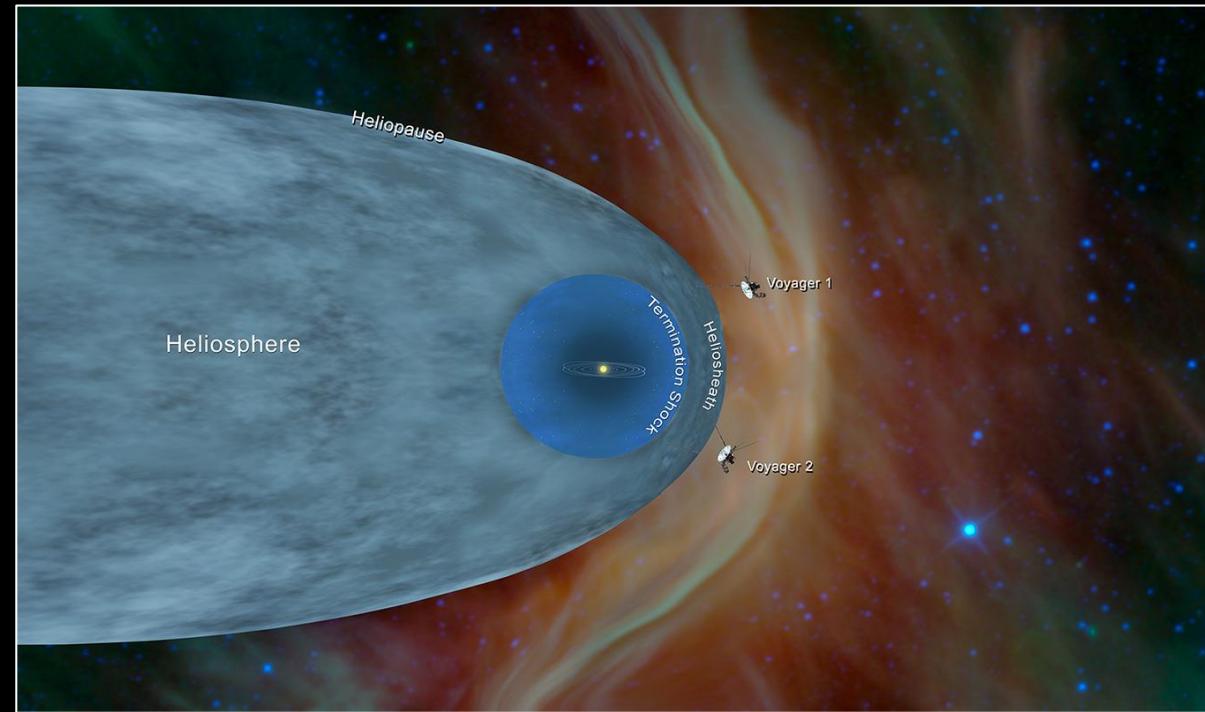


Beyond Solar System: Interstellar



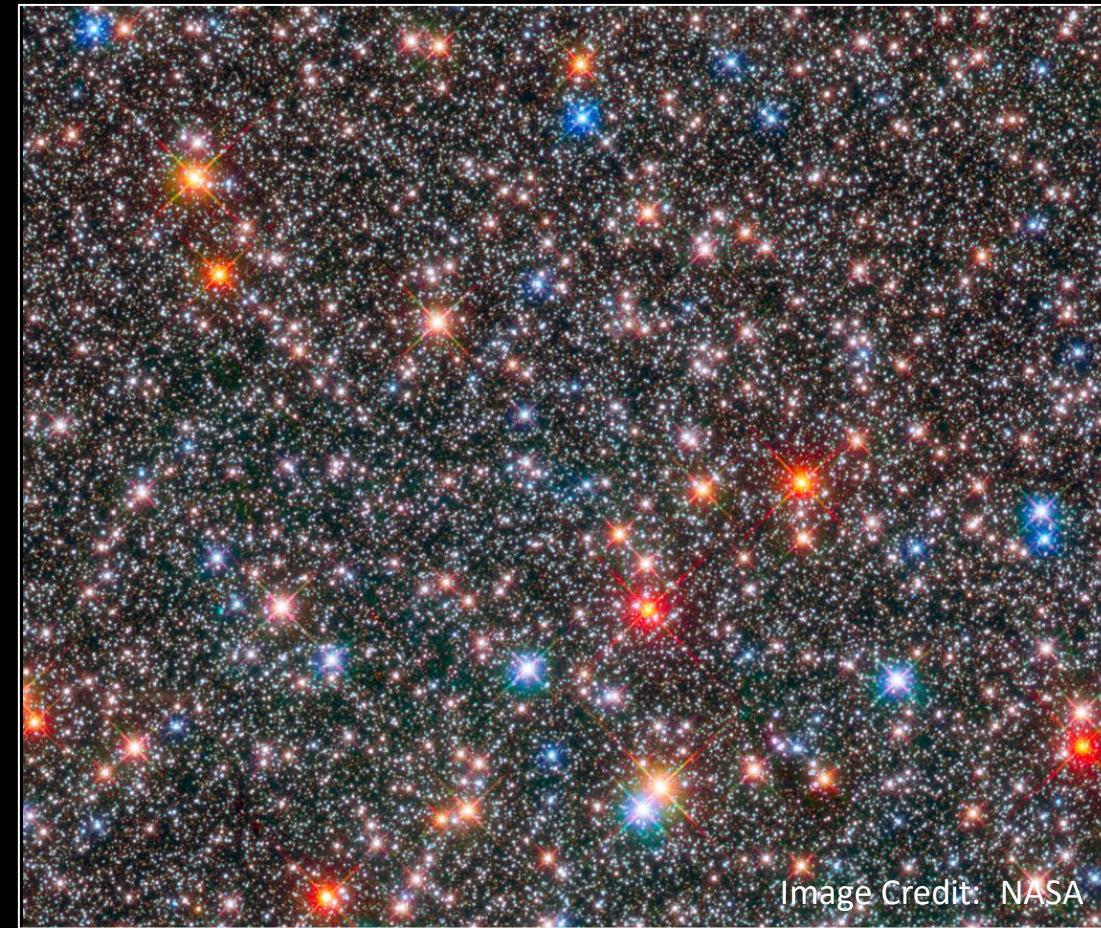
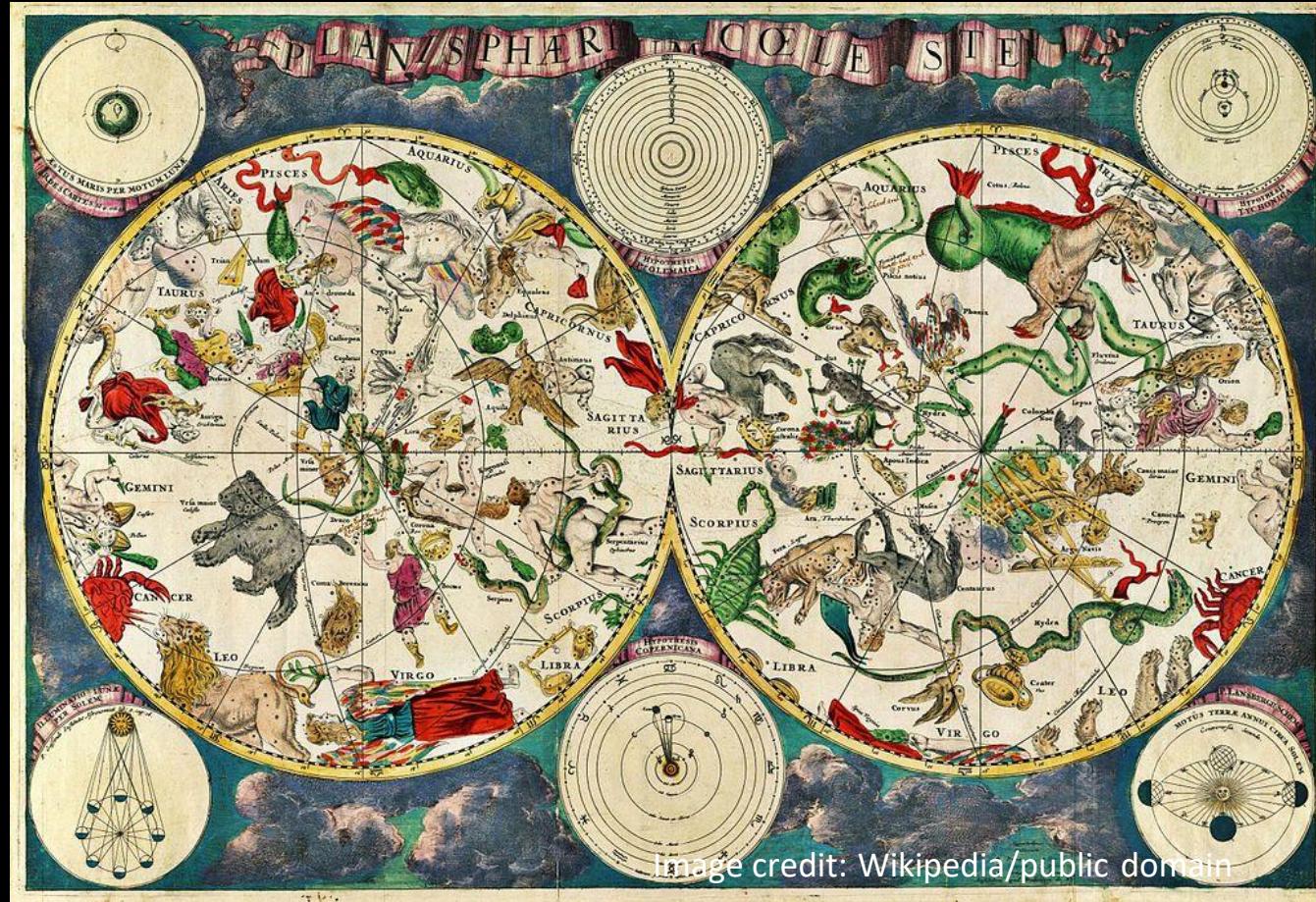


Our Sun in the Milky Way Model

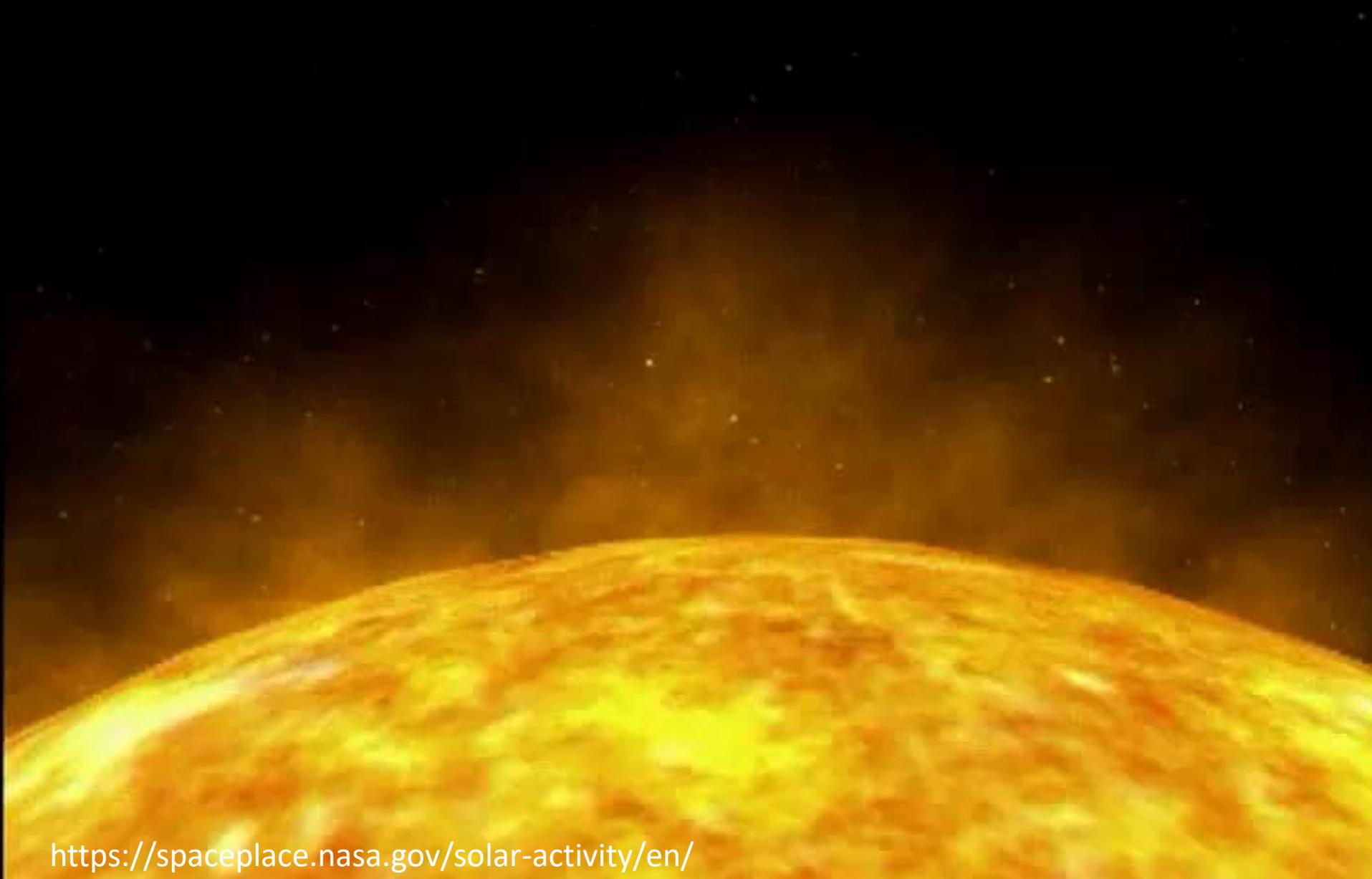


Images Credit: NASA

Our Night Sky Cartographic Improvements



The Solar Radiation Environment



<https://spaceplace.nasa.gov/solar-activity/en/>

Image Credit: NASA

Solar Flares & Coronal Mass Ejections

*Movies from the SOHO (Solar & Heliospheric Observatory) spacecraft
“Halloween Storms” – October 2003*

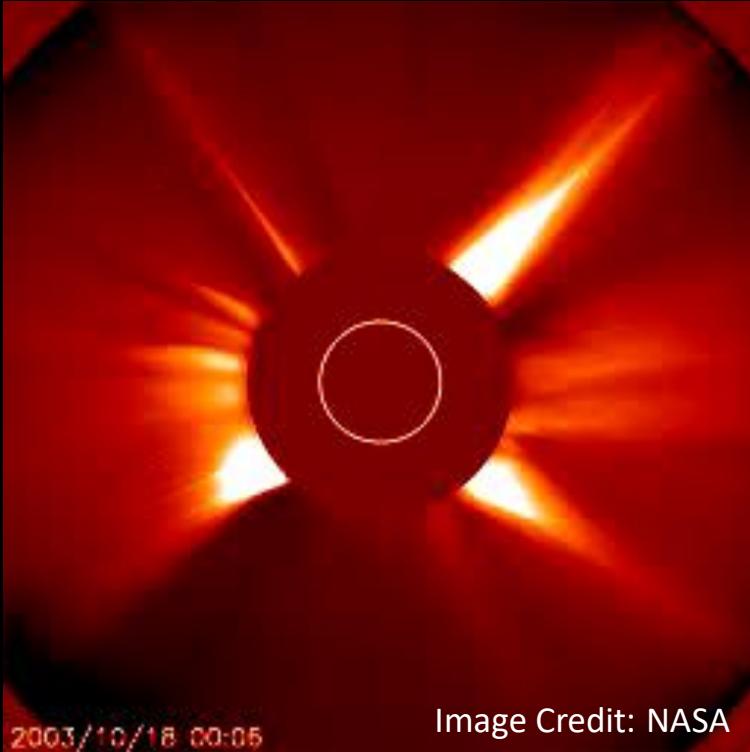


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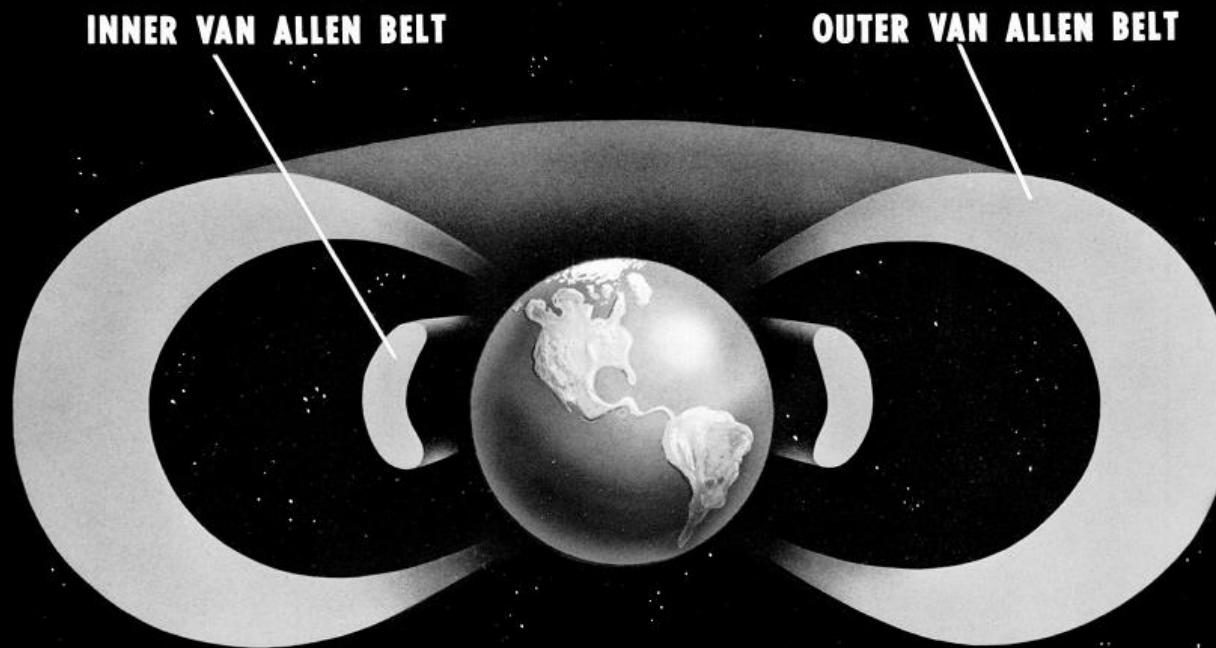


Image Credit: NASA

Instrument: Large Angle and
Spectrometric Coronagraph
(LASCO)

Instrument: Extreme Ultraviolet
Imaging Telescope (EIT)

Van Allen Radiation Belts



S61-479

NASA's Goddard Space Flight Center/Historic image of Van Allen Belts courtesy of NASA's Langley Research Center

Radiation Effects Limit Mission Duration

In most cases, amount of shielding reduces the dose rate



Image Credit: Microsoft Office Stock Images



Image Credit: Microsoft Office Stock Images

*Like a wear rate, a 20,000-mile versus 100,000-mile tire tread life
If one needs new tires in space, there is no one there to change them, yet.....*

Slowing Down Radiation Effects like a Time Machine

Intergenerational: Missions Extending Beyond our Lifetimes

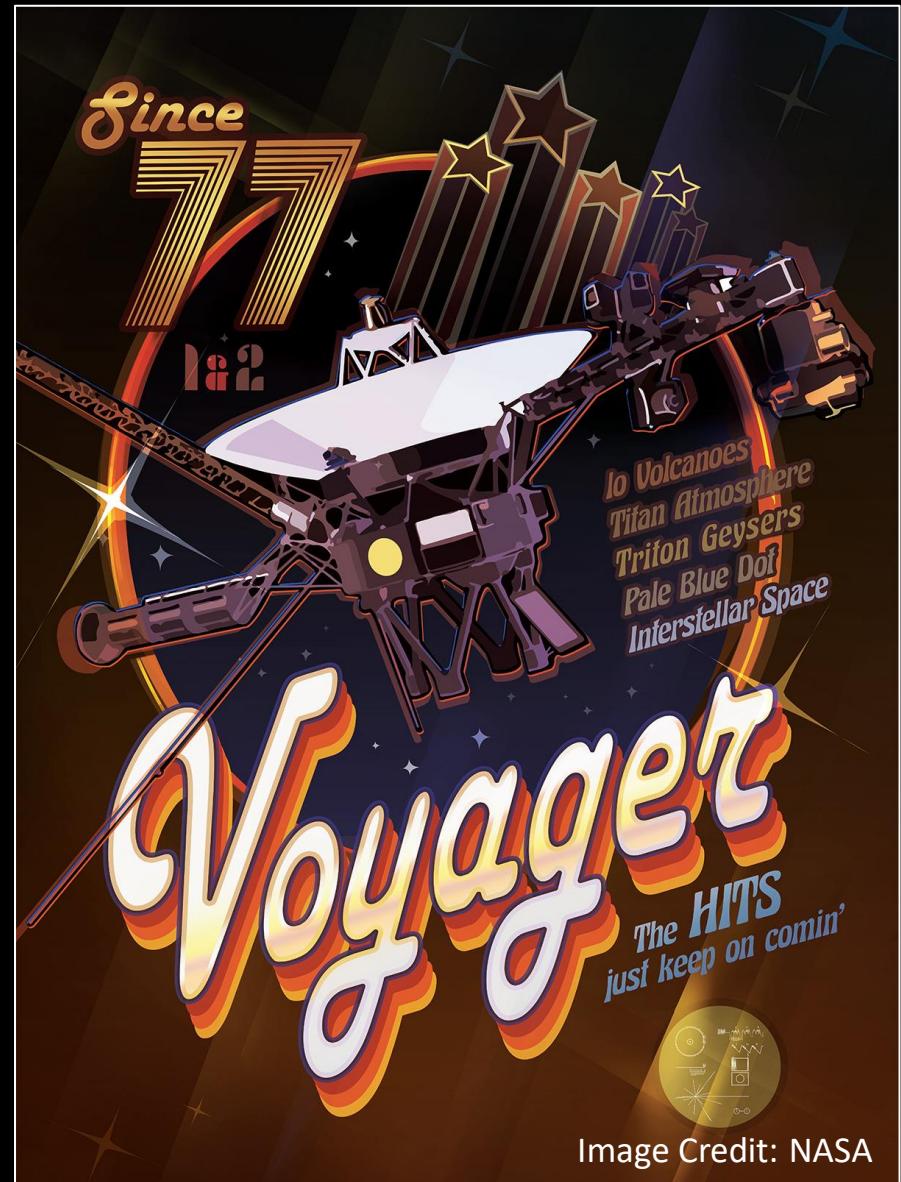


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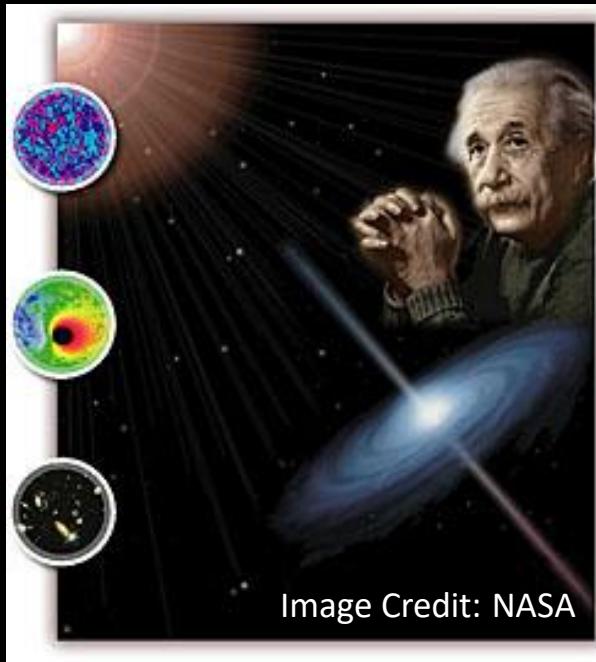


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NIST National Institute of Standards and Technology
U.S. Department of Commerce

THE OFFICIAL U.S. TIME

Daylight saving time begins on Sunday, March 13th at 2 a.m. (local time) - set clocks FORWARD one hour.

PACIFIC DAYLIGHT TIME PDT (UTC-7)	MOUNTAIN DAYLIGHT TIME MDT (UTC-6)	CENTRAL DAYLIGHT TIME CDT (UTC-5)	EASTERN DAYLIGHT TIME EDT (UTC-4)
12:10:19 P.M.	01:10:19 P.M.	02:10:19 P.M.	03:10:19 P.M.

Disco to Hip Hop Generations

Planting the Seeds of Multigenerational Research

- Develop and prepare small spacecrafts that can withstand solar radiation environment, galactic cosmic radiation, and long duration missions
- Nurture academic, government, and citizen interest
- Coordinate multigenerational effort and data availability



Image Credit: NASA

Small Spacecraft Missions: Increasing Complexity and Duration at a Fraction of the Cost of Larger Spacecraft

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Small Spacecraft Technology Program

Earth Science Technology Office

CubeSat Launch Initiative

CubeSats on Exploration Mission-1

Ames Small Satellite Portal

JPL Small Satellite Portal

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Solar System and Beyond
SIMPLEX Mission Small

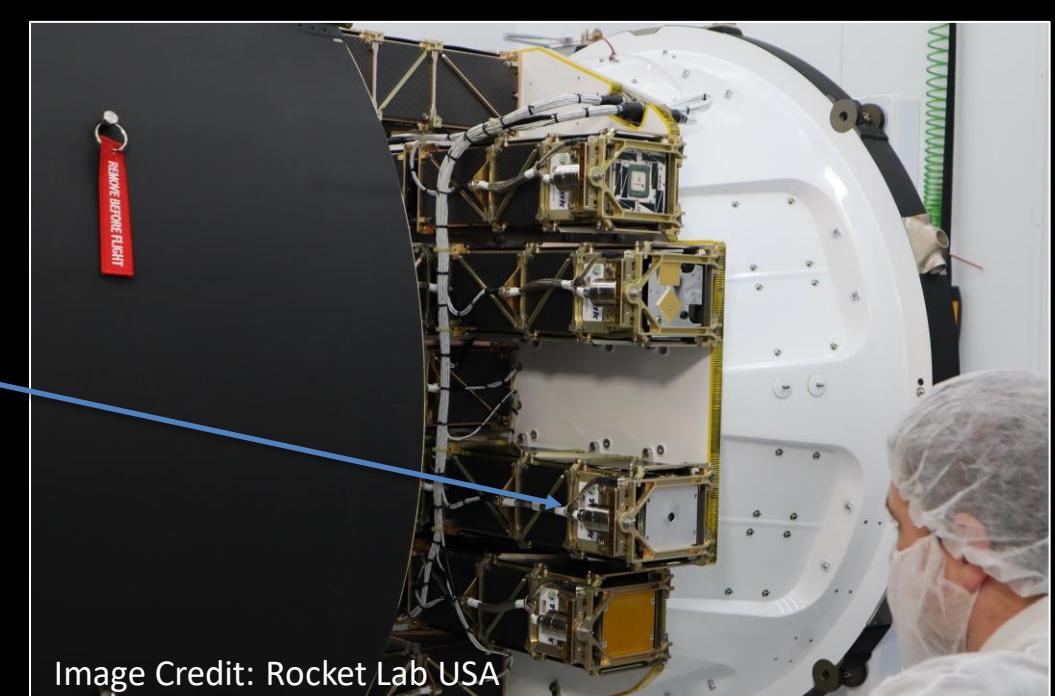
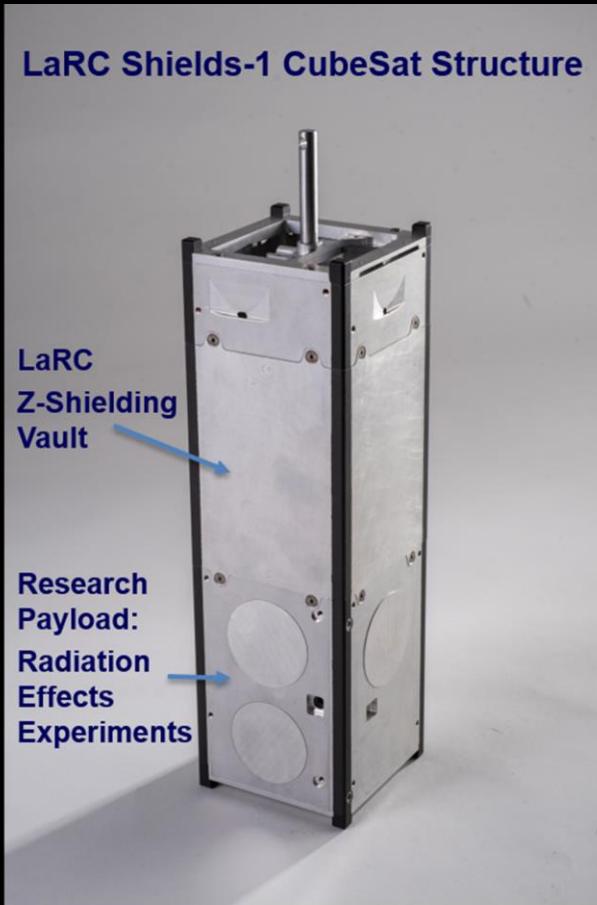
NASA Kennedy
ELaNa 31 Mission CubeSats

Solar System and Beyond
SIMPLEX Mission Small

Images Credit: NASA

Shields-1, Space Radiation Effects Experiments NORAD ID 43850

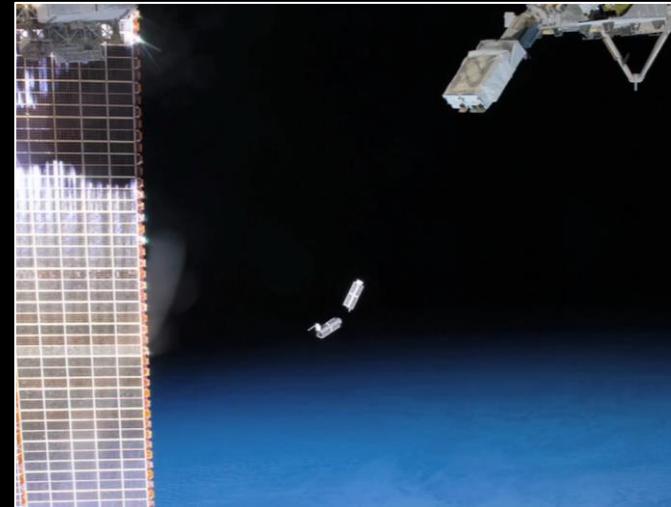
Presently, Shields-1 operates with LaRC Z-Shielding providing radiation protection for the electronics over 3 years in polar low earth orbit



<https://www.rocketlabusa.com/missions/completed-missions/elana-19/>
<https://www.youtube.com/watch?v=KZwLJMPuos8>
<https://www.youtube.com/watch?v=WSCAE-hEa9M>

CubeSat Market: \$0.5B-1B over 3yrs

- Over 1700 small satellites forecasted for 2017-2023 (www.spaceworksforecast.com)
- Over 500 over next 3 yrs into polar low earth orbit (PLEO) (www.spaceworksforecast.com)
- Typical CubeSats costs \$1-2M*
(https://esto.nasa.gov/techval_space.html)
**NASA ESTO Office reported it is \$1-\$1.5M per U at the SmallSat Conference and is updating its figure.*
- CubeSat value at risk: \$0.5-1B in the next three years alone



Voyager 1 and 2: Only Two Trajectories over Our Vast Solar System Boundary and the Rest of the Milky Way

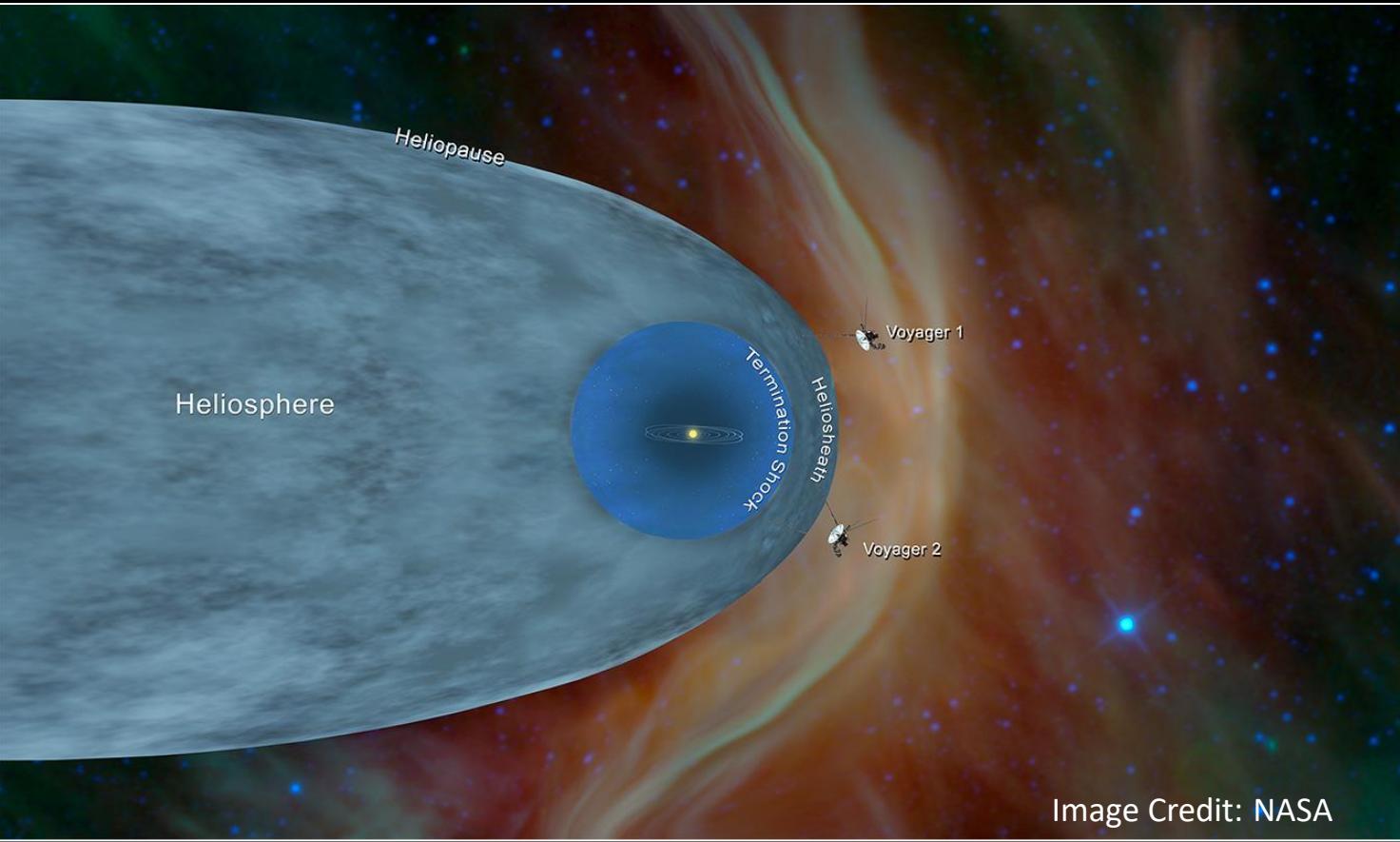


Image Credit: NASA

- Artist Depiction of the Heliosphere
- **Voyager 1 and 2 Not to Scale**
- \$865 Million through the Neptune Encounter in 1989
- Typical CubeSat Missions today \$3-6 Million
- Lower launch costs and Spacecraft Weights
- More Capability in a Small Package
- Capability for More Sustainable Missions at a fraction of the Costs of Larger Missions

Multigenerational Exploration and Modern Civilization History

- **Gifting Forward:**
 - The story of our existence in the Solar System, Milky Way, and Universe
 - Training our next Science, Technology, Engineering, and Mathematics Explorers
- **Engaging our Scientific Curiosity**
- **Adding to Peaceful Cooperation amongst Multiple Cultures and Countries**



Image Credit: www.nasa.gov



Image Credit: www.nasa.gov

References

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- B. Crain
- A. Goff (Luna Innovations)
- S. Princiotto (Teledyne)
- M. Wrosch (Vanguard Space)
- ELaNaXIX Mission NASA CubeSat Launch Initiative
- NASA Wallops Flight Facility CubeSat Ground Operations